Available online at www.sciencedirect.com
ScienceDirect
Procedia Engineering 127 (2015) 598 – 604
Procedia Engineering
www.elsevier.com/locate/procedia

International Conference on Computational Heat and Mass Transfer-2015

Hydrodynamic Modeling of Moored Ship Motion in an Irregular Domain

Prashant Kumar[a]*, Kim Kwang Ik[b]

[a]National Institute of Technology, Department of Applied Sciences, Delhi
Sec-A7, Institutional Area, Narela, New Delhi-110040, India
[b]Department of Mathematics, Pohang University of Science and Technology,
Pohang-790784, South Korea.

Abstract

In this study, a hydrodynamic model for the analysis of moored ship motion is presented in a realistic harbor with highly irregular geometry. An accurate description of the harbor geometry, bathymetry and the associated wave's characteristics such as diffraction, refraction and partial reflection is required for the analysis of moored ship motion. Further, Fluid domain is divided into bounded, unbounded or open sea and ship region. In each region, wave field is determined by using Boundary Element Method (BEM) with the corner contribution and Chebyshev point discretization. Then, the hydrodynamic coefficient such as added mass and damping coefficients were determined based on the equation of motion with six degree of freedom, which represent the six different component of moored ship motion as surge, sway, heave, roll, pitch and yaw. The current numerical model is validated through previous well defined model based on moored ship motion. Moreover, current numerical scheme is implemented on realistic Pohang New Harbor (PNH), which is situated in Pohang city, South Korea to analyze the wave field in ship region under the various resonance frequencies for monochromatic incident waves.

Peer-review under responsibility of the organizing committee of ICCHMT – 2015

Keywords: Moored ship motion; Boundary Element Method (BEM); Hydrodynamics coefficient; Pohang New Harbour (PNH).

* Corresponding author. Tel.: +0-000-000-0000 ; fax: +0-000-000-0000 .
E-mail address: prashantkumar@nitdelhi.ac.in

1877-7058
Peer-review under responsibility of the organizing committee of ICCHMT – 2015
doi:10.1016/j.proeng.2015.11.350

1. Introduction

Harbours are designed to obstruct the incoming waves from the open sea and to protect moored ships and offshore structures. The high amplitude incident waves generated by seasonal typhoon are observed in the industrial PNH, which is hazardous to offshore structure, interior boundary of harbour and moored ship. The PNH is situated in southeast part of South Korea, which is designed to support the POSCO steel corporation. Moored ship in the harbour might experience the different external forces such as wind force, current force, and the hydrodynamics forces due to incident wave from various directions. A small portion of incident waves are radiated through entrance to the open sea and remaining portion is diffracted, refracted and partially reflected repeatedly by boundary of moored ships and the interior boundary of the harbour.

Many researchers have developed several numerical schemes to analyse the hydrodynamic response of moored ship in a real harbour. However, these approaches are model based which are useful to predict the wave field at moored ship in the harbour of arbitrary complex geometry. A numerical scheme was developed by Oortmessen [1] to analyse the moored ship in shallow water waves in a harbour. Sawaragi and Kubo [2] investigated Boundary Integral Equation Method (BIEM) using three dimensional (3D) Green's functions, which is applied on a rectangular floating body in a rectangular harbour. Takagi and Naito [3] independently developed a mild slope equation model applied to the 2-D geometry with the variation of bottom topography by using a Finite Element Method (FEM). Further, a combined method is formulated with the combination of 3-D BEM and 2-D FEM, which is applied on moored ship motion in a harbour [4, 5]. A hybrid Boussinesq panel method is utilized to predict the various modes of moored ship motion in restricted water depth [6, 7, 8]. Based on the field observation, a hybrid potential theory is investigated to predict the moored ship motion induced by tsunami waves [9, 10]. Recently Kwak and Pyun [11] used CGWAVE model to analyse the moored ship motion in PNH.

In this paper, we have designed a mathematical model for the hydrodynamics of moored ship motion, in which boundary corner contribution and Chebyshev point discretization is utilized. The main analysis consists of two parts. Firstly, the wave field for bounded and unbounded region are evaluated under the partial reflection boundary conditions [12] for different resonant frequencies waves with various directions. Further, applying the constant density assumption under the consideration of linearized kinematic and dynamic surface boundary conditions, Laplace equation is solved by using 3-D BEM to obtain the six different modes of moored ship motion in the ship region. Secondly, the present numerical simulation result is validated through the comparison with the previous well defined model given by Sawaragi and Kubo [2] and Takagi and Naito [3]. Then, the present numerical model is applied on realistic PNH domain under the resonance conditions for various monochromatic waves.

2. Model Formulation

The fluid domain is divided into three regions, i.e., bounded region (harbor), unbounded region (open sea) and the ship region. The bounded region Ω_b with uniform depth h_2 is surrounded by the harbor wall S_W including the harbor entrance E_1E_2. The unbounded region Ω_u with uniform depth h_1 is the open sea region, which includes the exterior coastal boundary (see Fig. 1). The ship region Ω_s with uniform depth h_3, which includes the moored ship S_M enclosed by semi-circular boundary S_0 with sea floor S_B. The lateral and front view of moored ship is shown with incident wave angle α onto the moored ship. The rectangular ship with length (L_S), width (B_S), height (H_S) and draft (D_S) located at the boundary of the harbor to analyze the moored ship motion (see Fig. 1).

2.1. Governing Equation

Firstly, we utilized Helmholtz equation in bounded and unbounded region to determine the wave induced oscillation in an arbitrary shaped harbour consider the corner contribution and Chebyshev Point discretization ([13]). Then, velocity potential is evaluated in the bounded and ship region. In ship region, the potential function is expressed in terms of diffraction and radiation potential as following

$$\phi^{(3)}(x,y,z,t) = \mathrm{Re}\left[\left\{\phi_0(x,y,z) + \sum_{j=1}^{6}\phi_j(x,y,z)\right\}e^{-i\omega t}\right], \tag{1}$$

where $\phi_0 = \phi_I + \phi_R + \phi_s$ is denotes the diffraction potential, in which ϕ_I is the incident wave potential, ϕ_R is the reflective wave potential and ϕ_s is the scattering wave potential. Radiation potential ϕ_j satisfies the Laplace equations such that

$$\nabla^2 \phi_j = 0 \quad \text{for} \quad j = 0,1,2...6 \tag{2}$$

The following boundary conditions acting on the moored ship S_M are summarized as follows:

a) Kinematic free surface boundary condition is expressed as

$$\left(\frac{\partial \phi_j}{\partial z}\right) - \left(\frac{\omega^2}{g}\right)\phi_j = 0 \quad \text{for} \quad j = 0,1,2...6 \tag{3}$$

b) Boundary condition at bottom of sea S_B and the bottom of the ship surface S_M is given by

$$\left(\partial \phi_j \big/ \partial z\right) = 0 \quad \text{for} \quad j = 0,1,2...6 \tag{4}$$

c) Due to linearization, the following boundary condition may apply to moored ship such that

$$\begin{aligned} \left(\frac{\partial \phi_j}{\partial n}\right) &= -i\omega n_j \quad \text{on } S_M \quad \text{for} \quad j = 1,2,3. \\ \left(\frac{\partial \phi_j}{\partial n}\right) &= -i\omega (r \times n)_{j-3} \quad \text{on } S_M \quad \text{for} \quad j = 4,5,6. \end{aligned} \tag{5}$$

Where n is outward normal vector as (n_1, n_2, n_3) and r is position vector acting on S_M. The solution of Eq. (2) is determined by using Green's identity formula to the fluid domain Ω_s .

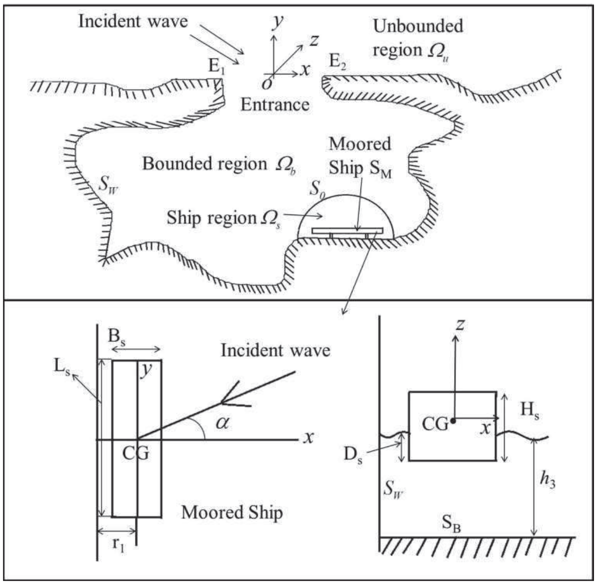

Fig. 1. In upper part: Model sketch of irregular geometry of harbor including bounded, unbounded and ship region is shown along with moored ship S_M on the boundary while in lower part, bird view of a front view of moored ship is given.

Then a 3-D BEM model is employed as summarized by Ohyama and Tsuchida [4], the following form of boundary integral is obtained as

$$\phi_j(x, y) = -\frac{1}{C}\int_{S_0}\left\{\phi_j \frac{\partial G}{\partial \vec{n}} - G\frac{\partial \phi_j}{\partial \vec{n}}\right\} dS_0 - \int_{S_M \cup S_B}\left\{\phi_j \frac{\partial G}{\partial \vec{n}} dS + \int_{S_M} n_j G dS, \right. \tag{6}$$

where the value of parameter C is 2π for $(x,y)\in S_0$ and 4π for $(x,y)\notin S_0$ and G represent a Green function. The equation of motion for body dynamics can be written under the above assumptions in the following matrix form

$$\sum_{j=1}^{6}\left[-\omega^2(M_{ij}+a_{ij})+i\omega b_{ij}+C_{ij}\right]\zeta_j = F_{ex,j}, \tag{7}$$

where a_{ij} and b_{ij} are the added mass and damping coefficient and ζ_j is wave amplitude with frequency ω. The buoyancy matrix C_{ij}, inertia matrix M_{ij} and wave exciting force is given by Newman [14].

3. Verification of the Model

The current model is compared with previous models, which are applied by Takagi and Naito [3] and Yoo [15] as shown in Fig. 2. In this model, the length of model ship is 1 m, width is 0.4 meter and height is 0.3 m, and draft is 0.2 m. The dimension of rectangular harbour is taken as length is 5 m, width is 3 m and depth is 0.5m. In Fig. 2, simulation result shows the good agreement with previous well studies. Thus the present numerical model can be implemented on to the real harbour to analyse the moored ship motion. The simulation results show the good agreement with previous well defined models.

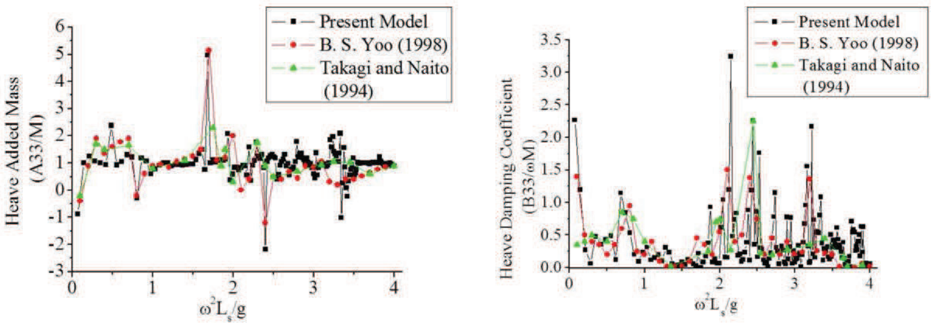

Fig. 2. The current numerical model is compared with previous models such as Takagi and Naito [3] and B.S. Yoo [15] for validation of the numerical scheme.

4. Simulation results for moored ship Motion

The numerical simulations have been carried out on PNH to analyse the moored ship motion, which is specified as translational motion and rotational motion. Translational motion includes as surge, sway and heave component of added mass and damping coefficient as shown in upper part of Fig. 3. Further, simulation results for the rotational motion, i.e., the roll, pitch and yaw component of added mass and damping coefficient are shown in lower part in Fig. 3. The non-dimensional frequency $\omega^2 L_s / g$ is taken along x-axes with frequency difference 0.02. Frequency difference is taken small enough to ensure the numerical accuracy of simulation results for moored ship motion. The peaks height varies with respect to each resonant mode of ship motion. At these resonant modes, moored ship motion has higher oscillation then the rest of frequencies. In the next section, the wave field in the ship region is analysed for various resonance modes obtained in the bounded region.

On the basis of actual topography and bathymetry data of PNH, the numerical simulation has been conducted to figure out the characteristics of the ocean surface wave in the interior domain of the PNH at various incident wave directions. The whole boundary of PNH is discretized regularly by using Chebyshev points into N=1002 segments with N_1=68 entrance segment division. The location of moored ship S_M inside the PNH is shown in 4(a) with discretized boundary. The numerical simulations are conducted to figure out the characteristics of the ocean surface wave in the ship region for wave of different resonance modes and directions. In the ship region, the first three resonance mode are obtained at non dimensional wave number k_1=2.87, k_2=3.70 and k_3=5.91 [13]. Thus the wave elevation in the ship region has been numerically computed for the incident waves coming from south direction towards entrance with incident angle $\alpha = \pi / 4$, which is shown in the Fig 4. The impact of incident waves on the moored ship from various resonance modes at particular direction is observed.

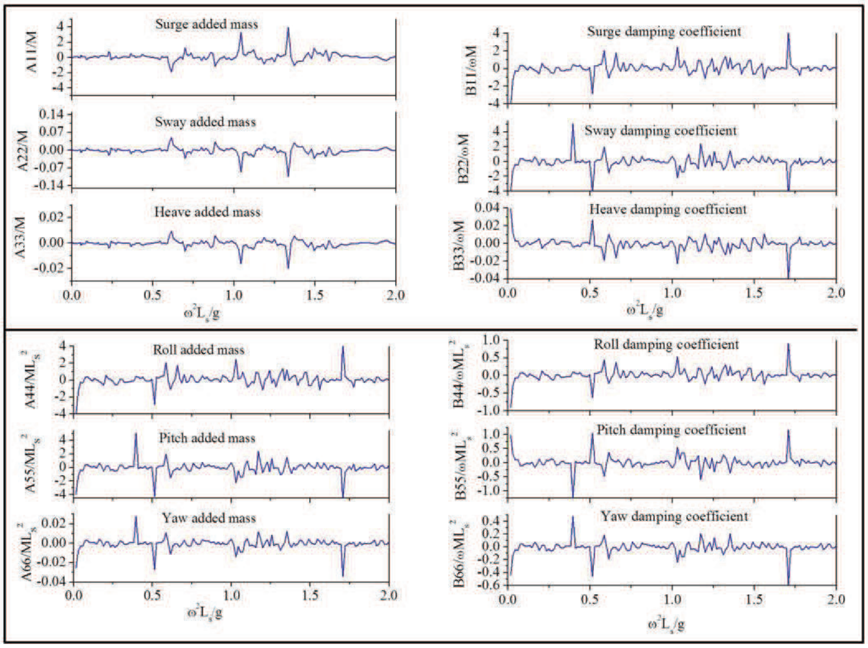

Fig. 3. In translational motion, surge added mass (*A11/M*), sway added mass (*A22/M*), heave added mass (*A33/M*), surge damping coefficient ($B11 / \omega M$), sway damping coefficient ($B22 / \omega M$), heave damping coefficient ($B33 / \omega M$), roll added mass ($A44/ML_s^2$), pitch added mass ($A55/ML_s^2$) and yaw added mass ($A66/ML_s^2$). In rotational motion, roll damping coefficient ($B44 / \omega ML_s^2$), pitch damping coefficient ($B55 / \omega ML_s^2$) and yaw damping coefficient ($B66 / \omega ML_s^2$) have shown with non-dimensional frequency difference 0.01 for the multidirectional directional incident waves. Along *x*-axis non-dimensional frequency $\omega^2 L_s / g$ is taken, where, ω is the angular frequency, L_S is the length of model ship and *g* the gravitational constant.

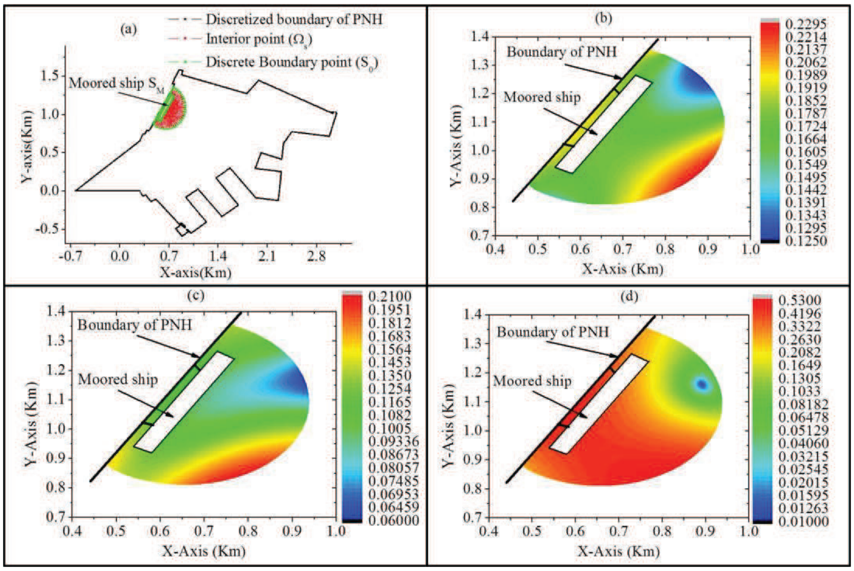

Fig. 4. Discretized PNH with moored ship S_M (a) Ocean surface wave field analysis of moored ship motion for the first three resonance modes k_1=2.87 (b) k_2=3.70 (c) k_3=5.91 (d), when directional incident wave propagate toward entrance at an incident angle $\alpha = \pi / 4$. .

5. Conclusion

In this paper, moored ship motion has been analyzed for the long waves of small amplitude from various directions under the various resonance conditions. The direction of the incident waves and resonance modes are crucial parameters to analyze the moored ship motion at fixed location inside the harbor. The corresponding frequencies related to resonance modes are known as resonant frequency, which are very significant to analyze the wave field around the moored ship. On basis of wave field information, the safe location can be found in the harbor or port stations. However, the main focus of the current research is to develop a computationally efficient, effectual and reliable model to predict the moored ship motion inside the harbor.

Acknowledgements

This research work is currently supported by Department of Applied Sciences, National Institute of Technology Delhi.

References

[1] G.V. Oortmerssen, The motions of a ship in shallow water, Ocean engineering 3 (1976) 221-255.
[2] T. Sawaragi, M. Kubo, The motion of a ship in a harbor basin, Proc. of 18th Int. Conf. on Coastal Eng. Cape Town, S.A. 1982, pp. 2743-2762.
[3] K. Takagi, S. Naito, Hydrodynamic forces acting on a floating body in a harbor of arbitrary geometry, International Journal of Offshore and Polar Engineering 4 (1994) 97-104.
[4] T. Ohyama, M. Tsuchida, Development of a partially three dimensional model for ship motion in a harbor with arbitrary bathymetry, Proc. Of 24th Conf. Coastal Engineering Kobe, Japan,1994, pp. 871-885.
[5] T. Ohyama, M. Tsuchida, Expanded mild-slope equations for the analysis of wave-induced ship motions in a harbor. Coastal Engineering 30 (1997) 77–103.
[6] H.B. Bingham, A hybrid Boussinesq panel method for predicting the motion of a moored ship, Coastal Eng. 40 (2000) 21-38.
[7] W. Molen, I. Wenneker, Time-domain calculation of moored ship motions in nonlinear waves, Coastal Engineering 55 (2008) 409-422.
[8] G. Bellotti, Numerical modeling of long waves amplification at Marina di Carrara harbour, Applied Ocean Research 48 (2014) 322-330.

[9] S. Sakakibara, M. Kubo, Characteristic of low frequency motion of ships moored inside ports and harbors on the basis of field observations Marine Structures 21 (2008) 196-223.
[10] S. Sakakibara et al., A hybrid potential theory for predicting the motion of a moored ship induced by large-scaled tsunami, Ocean Engineering 37 (2010) 1564-1575.
[11] M. Kwak, C. Pyun, Computer simulation of moored ship motion considering harbor resonance in Pohang New Harbor, Proc. of Ports 2013, Sealtle, Washington 2013, pp. 1415-1424.
[12] M. Isaacson, S. Qu, Waves in a harbour with partially reflecting boundaries, Coastal Engineering 14 (1990) 193-214.
[13] P. Kumar et al., Wave field analysis in a harbor with irregular geometry through boundary integral of Helmholtz equation with corner contributions, Computers & Fluids 88 (2013) 287–297.
[14] J.N. Newmann, Marine Hydrodynamics. The MIT Press; Cambridge, Massachusetts London England, 1977.
[15] B.S. Yoo, An analysis of ship motion in a harbor, The Ph.D. Thesis, Seoul National University, South Korea, total pp. 192, 1998.